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Failure Predictions for the Post-Closure Liability Trust Fund Analysis

Battelle Pacific Northwest Labs., Richland, WA

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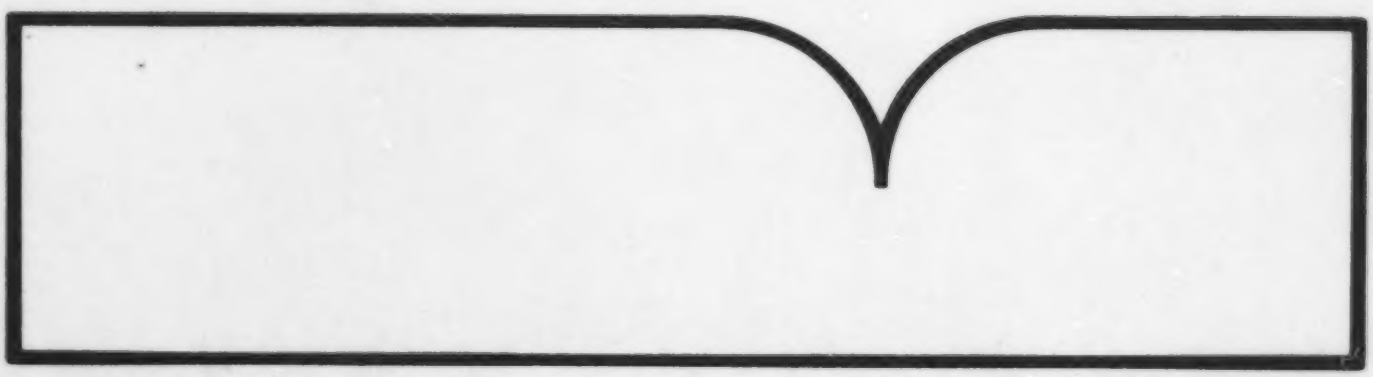

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FAILURE PREDICTIONS FOR THE POST-CLOSURE LIABILITY TRUST FUND ANALYSIS

by

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16. ABSTRACT

With passage of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) of 1980, Congress created two funds to assist in the restoration of areas contaminated with hazardous wastes. In addition to the better known "Superfund" which helps cover the cost of remedial action at abandoned or uncontrolled hazardous waste sites, Congress mandated the Post-Closure Liability Trust Fund (PCLTF). The latter fund is designed to cover the post-closure maintenance, monitoring and remedial action for sites closed under the Resource Conservation and Recovery Act (RCRA) regulations.

Congress charged EPA with preparing a report by December of 1984 which would identify required changes in funding base or the ceiling level to assure fund availability. EPA chose to construct that report on the basis of a coupled economic and geohydrologic model. The latter would predict when and how various representative facilities will fail while the former would estimate what the subsequent demands would be on the fund. The paper describes the failure prediction module of the overall model.

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INTRODUCTION

With passage of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) of 1980, Congress created two funds to assist in the restoration of areas contaminated with hazardous wastes. In addition to the better known "Superfund" which helps cover the cost of remedial action at abandoned or uncontrolled hazardous waste sites, Congress mandated the Post-Closure Liability Trust Fund (PCLTF). The latter fund is designed to cover the cost of post-closure maintenance, monitoring and remedial action for sites closed under the Resource Conservation and Recovery Act (RCRA) regulations. To be eligible, these sites must have displayed no evidence of contaminant migration over a five year post-closure period during which they were monitored according to the RCRA permit conditions. Upon acceptance into the fund coverage by EPA, the federal government accepts responsibility for remedial action costs, liability claims and all monitoring and maintenance costs above those required for post-closure procedures under the permit.

When the fund was created, congress chose to finance the PCLTF by imposing a tax on hazardous wastes. An arbitrary ceiling value of $200 million was placed on the fund. It was mandated that whenever the fund balance exceeded the ceiling in the previous year, the tax would be temporarily discontinued. Since the fund can be invested to generate income, it is possible that it will sustain itself. On the other hand, if demands are high, it is also possible that the fund will be insufficient to meet the demands placed on it in any given year. In order to determine the adequacy of the ceiling value of $200 million, Congress charged EPA with preparing a report by December of 1983 which would identify required changes in funding base or the ceiling level to assure fund availability.

EPA chose to construct that report on the basis of a coupled economic and geohydrologic model. The latter would predict when and how various representative facilities will fail while the former would estimate what the subsequent demands would be on the fund. The following paper describes the failure prediction module of the overall model.

GENERAL STRUCTURE

The failure/exposure prediction elements of the module are designed within the framework illustrated in Figure 1. In essence, the functional nodes rely on user supplied data, correlation data held within captive data banks, programmed analytical constructs for predicting continuous events (e.g., leachate movement), and Monte Carlo simulations to predict discrete probabilistic events (e.g., rainfall patterns). The individual algorithms employed, data sources, and assumptions made to render the module operable are discussed here for each structural component.

MODULE INPUTS

At the initiation of a simulation, the user supplies a base set of input information. These are supplemented by internally generated values to create the required suite of data outlined in Table 1. For inputs supplied by the user, default values have been programmed into the module and can be utilized whenever the user does not supply a preferred value. Some inputs are self-explanatory, others are discussed here with respect to their use and the default value, when appropriate.

The type of site is required to define the potential source term. Specifically, the site must be characterized by:

Number of layers;
Thickness of each layer (in cm);
Field capacity of each layer (in cm);
Saturation for each layer (in cm);
Probability that synthetic liners/caps will fail in any given month;
Probability that synthetic liner/cap is punctured at time 0.

The first four characteristics are either suppled by the user or obtained from an internal data base. To perform the latter option, the user must identify the site as one of seven standard designs considered by the module. The final two characteristics must be put in by the user. Default values are 0.25 for synthetic membrane liners, 0.05 for synthetic membrane covers, and 0.00 for asphalt and concrete liners and covers. These values were based upon limited data reporting actual landfill failures and should be revised over time

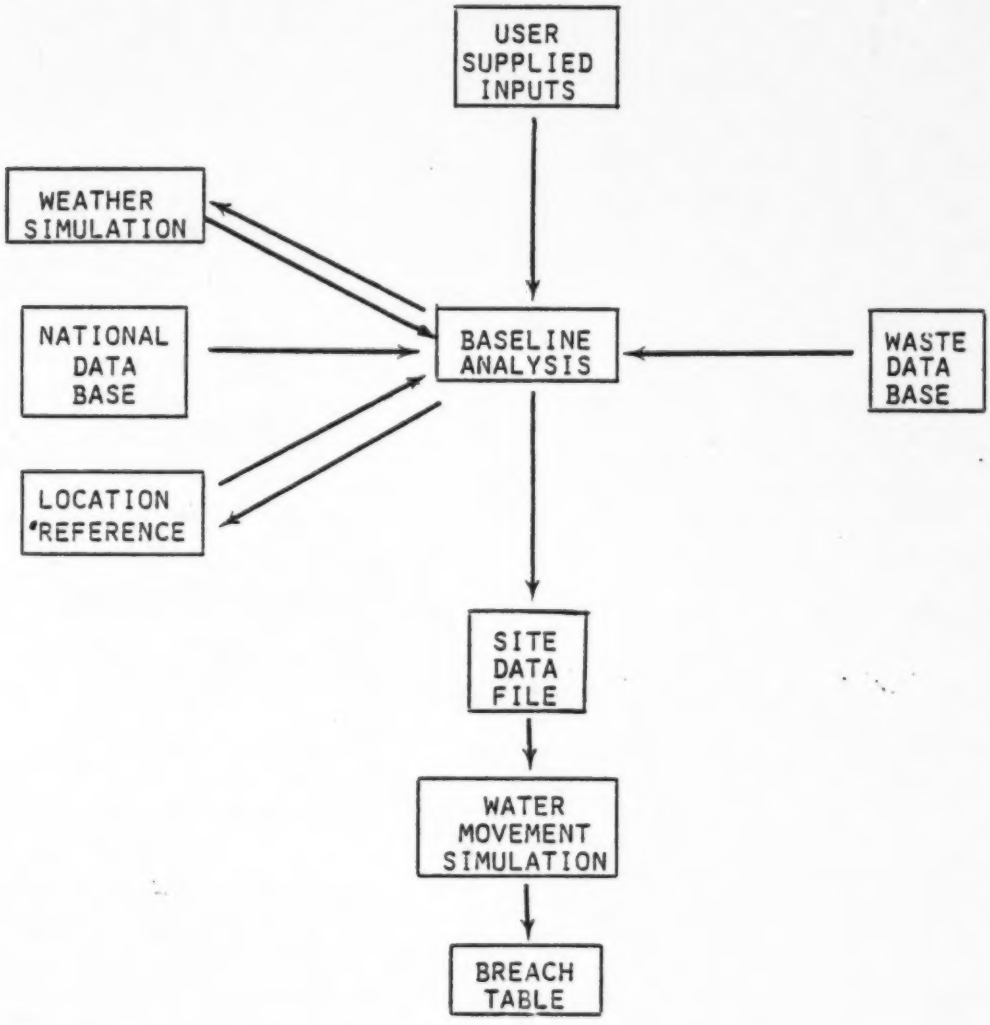

FIGURE 1. Relationship of Components in Failure Prediction Module

to reflect changes in both the data base and landfill construction practices as available. An identifier for each layer is assigned to designate the material type: waste-1, sand-2, clay-3, synthetic (e.g., plastic, asphalt, concrete)-4, soil-5. A separate identifier is used to denote the presence of a leachate collection system which would prevent upper layers from becoming saturated.

TABLE 1. Standard Inputs Required by the Failure Prediction Module

USER INPUTS NEEDED AT THE START OF A RUN:

- number of sites
- number of Monte Carlo replications
- base year (i.e. the time origin for the run [e.g. 1982])
- starting 'random' number seeds

VARIABLES THAT THE USER CAN RESET, AT THE START OF A RUN, INCLUDE:

- the probability that a synthetic cover fails at time zero
- the probability that a synthetic liner fails during a given month
- the probability that a synthetic cover fails during a given month
- the probability that a synthetic liner fails at time zero
- the amount of water which defines a breach when the monitoring is done inside the site

FOR EACH SITE OR FACILITY THE USER MUST DEFINE THE FOLLOWING:

- the site type (if the user picks one of the standard site types then the thickness, field capacity, saturation, starting water content, probabilities of synthetic liner failure, number of layers, type of layers [e.g. clay, sand, etc.], drainage and Type 1 breach flags are obtained from an internal site data base. If the user does not pick one of these standard types, he must supply his own values). Field capacity refers to the amount of moisture a medium will hold before the water begins to leak into the next lower layer. Starting water content refers to the amount of moisture in the layer to begin with.
- latitude and longitude
- number of wastes in the site and an EPA waste code for each waste
- date opened and closed
- data when post-closure care ceases
- date on which study ends for this site
- type of waste package (drum or sludge)
- width
- length
- distance to the monitoring well (which will be set to zero if monitoring is to be done at the site boundary)

THE COMPUTER WILL SUPPLY ALL OTHER VARIABLES. THE USER, HOWEVER, CAN OVERRULE THE COMPUTER AND SUPPLY ALTERNATIVE VALUES FOR THE FOLLOWING:

- seepage velocity range--velocity range of the aquifer, speed at which the water is moving
- distance to the drinking well and/or surface water
- choose to use the Blaney-Criddle Method over the Thornthwaite Method to characterize evapotranspiration (if the user does this, he must also supply all the parameters needed by the Blaney-Criddle Method)
- runoff coefficients--the fraction of precipitation which runs off the surface rather than infiltrates into the soil
- erosion
- effective porosity range--the range of values defining pore or void space in the soil; this is the space between soil particles through which soil moisture can flow
- depth to ground water range
- field capacity of the top soil
- the amount of water which defines a breach at the monitoring 'site' when the monitoring site is in the site
- random number seeds for the climate calculations
- water quality of the uppermost aquifer
- aquifer thickness

If the above data are not available for a given site, the design is specified from a previous module in the overall model on the basis of probability functions for seven prototypes such as that illustrated in Figure 2. If this approach is taken, the thickness of each layer can be specified independently. Clay lined and capped landfills, with or without leachate collection systems, are the most common site types selected. Permeability properties for each layer are accounted for as noted in the narrative on water movement simulation. While the seven prototype designs are

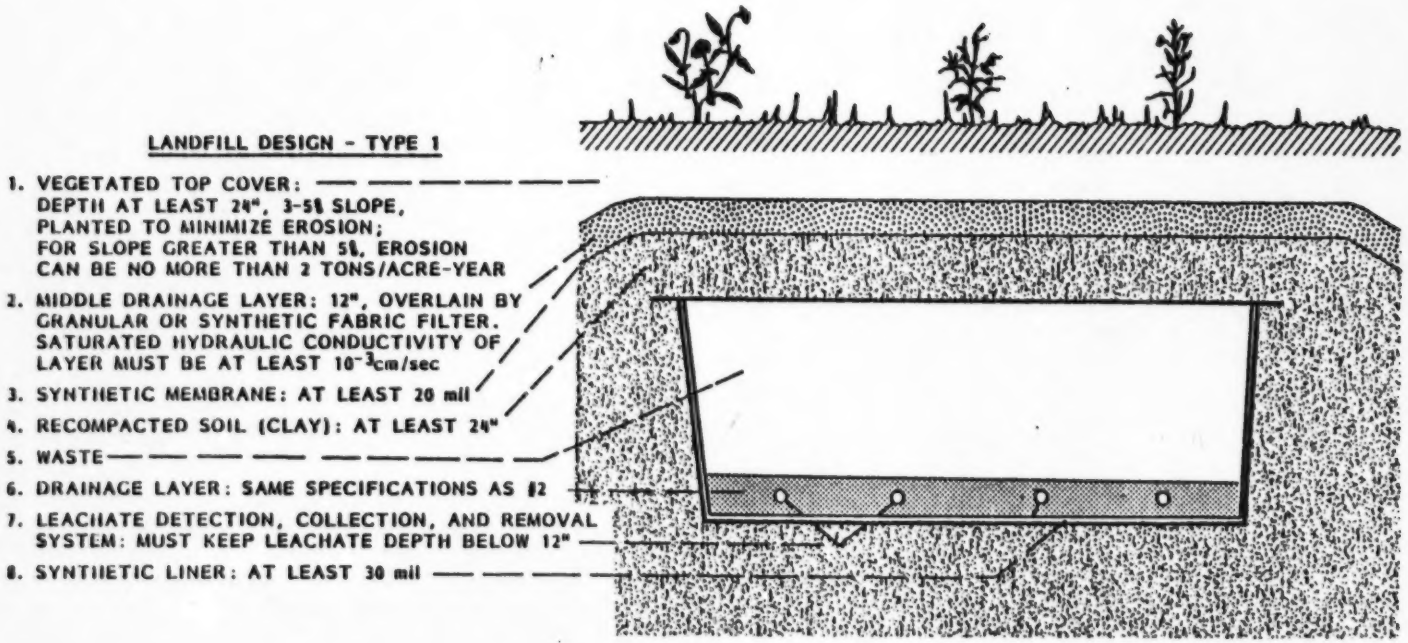
LANDFILL DESIGN - TYPE 1
1. VEGETATED TOP COVER: DEPTH AT LEAST 24", 3-5% SLOPE, PLANTED TO MINIMIZE EROSION; FOR SLOPE GREATER THAN 5%, EROSION CAN BE NO MORE THAN 2 TONS/ACRE-YEAR
2. MIDDLE DRAINAGE LAYER: 12", OVERLAIN BY GRANULAR OR SYNTHETIC FABRIC FILTER. SATURATED HYDRAULIC CONDUCTIVITY OF LAYER MUST BE AT LEAST 10^{-3}cm/sec
3. SYNTHETIC MEMBRANE: AT LEAST 20 mil
4. RECOMPACTED SOIL (CLAY): AT LEAST 24"
5. WASTE
6. DRAINAGE LAYER: SAME SPECIFICATIONS AS #2
7. LEACHATE DETECTION, COLLECTION, AND REMOVAL SYSTEM: MUST KEEP LEACHATE DEPTH BELOW 12"
8. SYNTHETIC LINER: AT LEAST 30 mil

FIGURE 2. Prototype Landfill Design - Type 1

for landfills, land farms and impoundments can also be evaluated by inputting the proper design dimensions and characteristics at closure. These sites are not modeled during operation since major modifications in waste characteristics will occur before these facilities can be closed. The latitude and longitude are input to specify the location of the site. This allows data to be withdrawn from the national data base from the appropriate region of the country and thus insures proper consideration of site-specific features.

EPA wastes codes must be specified for the wastes expected at a given site. While the code designation provides no input directly applicable to subsequent analyses, it identifies a discrete waste type which offers entry to an internal data base which can subsequently specify toxic constituents of concern and their properties which will affect transport and fate.

Dates of opening and closure are specified to indicate: (1) when the face is first opened and, therefore, allowed to collect precipitation, (2) how long the face is open; and (3) when the cap is emplaced. The date when post-closure care is terminated is equated with the time when leachate collection is terminated and erosion may proceed unabated. This assumption may be changed by the user to reflect the fact that leachate collection may cease when the cap is emplaced. Leachate generation and migration will begin when the site opens as will the aging process for any synthetic liners. Waters of infiltration will accumulate at a faster rate while the site is in operation because of the lack of a low permeability cap. After closure, the cap will be in place and infiltration will be reduced. Leachate migration can be substantial during operation. Hence, it must be tracked from the opening date. If a breach occurs prior to closure, the site may not qualify for the PCLTF. At a minimum, some form of repair will be required. All breaches are of direct interest to the analysis.

The length of run is specified by the user upon activating the model. This is the period of time following closure that the model will check for breaches. Simulation will stop at a date equal to the sum of latest closing date and the length of run.

The probability of liner failure refers to the density function to be employed in determining when a synthetic membrane liner is likely to fail

through natural degradation. This is separate from the probability of improper installation or puncturing during site operation (failure at time zero). It addresses the finite life of a properly installed membrance due to chemical degradation and natural forces. The user may specify a value for this probability or may choose to rely on the preprogrammed default values.

Internally Held Inputs

In addition to inputs supplied by the user, the module requires waste and geography specific inputs to conduct the analysis. These are held in a data base internal to the module itself.

Waste Specific Data. The EPA waste identifier codes specify the waste type or source. For the analysis required here, information is needed on the constituents in those wastes and their properties with respect to transport and fate in the environment. As a consequence, a data base has been generated to provide the desired inputs on a call-up basis.

For each waste code, toxic constituents were identified for the purposes of subsequent modeling of breaches. For each of the above constituents, data were compiled on solubility, drinking water or priority pollutant criteria levels, detection limits, octanol-water partition coefficients(1) (organics), and Kd values (inorganics).(2) With respect to toxicity criteria based on carcinogenesis, the 10^{-6} risk level value was used. (The 10^{-6} risk level is defined as the concentration at which exposure over a lifetime would result in one additional case of cancer in 10^{6} people.) The above physical constants were found in the "Background Document-Listing of Hazardous Wastes," unpublished, November 14, 1980, and its reference material: Dawson, G. W., C. J. English, and S. E. Petty. "Physical-Chemical Properties of Hazardous Waste Constituents," U.S. EPA, March 5, 1980.

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(1) An octanol-water partition coefficient represents the degree to which a chemical will distribute itself between water and octanol when shaken in a mixture of the two. It is used as a measure of a chemical's affinity for water as opposed to organic fluids.

(2) "Kd" is a parameter used to represent the distribution of a chemical between the soil and water in a given location at equilibrium, i.e.,

$$Kd = \frac{\text{concentration in soil}}{\text{concentration in water}}$$

Average detection limits of 10 µg/l for organics and 20 µg/l for inorganics were obtained from EPA's, "Guidelines Establishing Test Procedures for the Analysis of Pollutants; Proposed Regulations," (Federal Register, 69464-69575, Monday, December 3, 1979).

In addition, data are entered on the taste and odor threshold, the total dissolved solids (TDS) and total organic carbon (TOC) levels associated with all constituents in a waste to denote when indicator parameter or organoleptic properties would lead to detection of leakage in monitoring or portable wells.

The detection of a breach is based on arrival of mobile species at the point of detection. Detection may constitute discovery of positive values during monitoring or the onset of health effects due to toxic levels. Therefore, the most important constituent(s) in each waste will be the "early arrival" contaminant(s), i.e., those constituents which will first arrive at the monitoring or potable well in detectable or toxic concentrations. Recognizing this, (a) representative chemical(s) were identified for each waste accomplished by comparison of solubility, detection limit, toxicity criteria, and data on interactions with soil (attenuation). For consideration of breaches defined by arrival of detectable levels, the ratio of the solubility (S) and the detection limit (DL) were derived (S/DL) to indicate how much dilution and attenuation is necessary for each constituent before leachate will not produce a detectable level at the monitoring well (it is assumed that all constituents are leached from the site at their water solubility). Detection may be by analyses, by taste and odor, or by indicator parameter. Similarly for breaches defined by toxicity considerations, the ratio of the solubility (S) and toxicity criteria (TC) were derived (S/TC) to indicate the level of dilution and attenuation necessary to prevent a toxic level from occurring at the monitoring well. For organic chemicals, the octanol-water partition coefficient (P) is converted into Koc[1] using the Karichhoff relation ($\log Koc = 0.02 + 0.94 \log P$) which is subsequently employed to calculate a Kd (soil-water partition coefficient) for organic contaminants assuming an average

(1) "Koc" is the distribution coefficient adjusted to the organic carbon content of the soil.

$$Koc = \frac{\text{concentration in soil organic carbon}}{\text{concentration in water}}$$

soil organic content of 2 percent. Kd's are fed directly to subsequent modeling algorithms to designate soil attenuation. The Kd value is specified to indicate soil attenuation for inorganic constituents. No degradation is accounted for in the transport model. It is assumed that groundwater is abiotic (i.e., has no active biological community as a result of filtration of bacteria by the soil and potential toxicity of leachate) and, therefore, does not subject contaminants to biodegradation. Photodegradation (decomposition sponsored by the presence of light, e.g., sunlight) is also eliminated in groundwater systems. Hydrolysis and chemical oxidation may still occur, but since the worst case contaminants are of primary interest, constituents with significant degradation rates are not retained as indicator chemicals.

For each waste code, the values [Log (S/DL) - Log (Kd)] and [Log (S/TC) - Log (Kd)] were calculated for each constituent. The constituents yielding the highest values were designated the "early arrival" contaminants for use in subsequent analyses since they will display the greatest speed in moving through the environment. Therefore, the one or two constituents with the highest value are employed to designate the properties of a given waste type. For a site receiving more than one waste, the values are compared between wastes and the constituents with the greatest speed employed for subsequent modeling. In essence, this process distills the modeling effort to one of following the "early arrival" chemicals for indicator parameters, the sum of all constituents' solubilities are employed.

In addition, wastes are characterized by the number of compound classes present and the total organic content. The compound classes of constituents in the waste are designated as inorganic, polar organic and non-polar organic to assist in predicting liner failure. Synthetic liners are often only effective for a single class of chemical. Therefore, synthetic liner life is given a shortened range when more than one category of chemicals is exposed to organic chemicals (Anderson, Brown, and Green, 1982). Therefore, in sites receiving these materials, a permeability change of two orders of magnitude is applied.

Geography Specific Data. Site specific data on environmental factors are housed in the National Data Base. This information file contains pertinent hydrogeological, geological and meteorological data registered by longitude and

latitude. In this way, when a given site is identified by its geographic coordinates, the model can access the National Data Base to determine the appropriate environmental input data. Specific parameters included in this data base are listed in Table 2.

TABLE 2. Inputs Included in the National Data Base

Temperature Profile (°C) - monthly mean and standard deviation
Precipitation Profile (cm/mo) - monthly mean and standard deviation
Depth to Groundwater (cm)
Gradient/Porosity (dimensionless)
Hydraulic Conductivity (cm/sec)
Distance to the Drinking Well or Surface Water (cm)
Overburden Field Capacity (cm/cm)
Erosion Loss (cm/mo)
Runoff Coefficient (dimensionless)
Aquifer Water Quality (µg/l)
Aquifer Thickness

A reference file was added as an additional element in the geography specific data base. This cross-referenced file identified the FIPS code, county, and latitude and longitude for the county seat for all counties. This was necessary to register the erosion loss data which was identified by FIPS code. The cross reference was retained on the data base to facilitate addition of new data not registered by latitude and longitude. It can also be utilized to locate sites when only the county or FIPS code are given.

RELATIONSHIPS AND FUNCTIONS

The failure prediction is carried out through a number of relations and functions as provided by the elements or submodules described as Weather Siumulation, Baseline Analysis, Site Data file, and Water Movement Simulation in Figure 1.

The Weather Simulation is accomplished utilizing a random draw or Monte Carlo Technique. The monthly average and standard deviation values for

temperature and precipitation are used to create a normal distribution of probable occurrence for each month of the year. A pseudo-random number generator program is then employed to select a value for each month of the simulation method. This is done for each of the primary weather stations in the U.S. Since the program package utilizes a congruential method, the entire weather pattern for a simulation can be retained by putting the starting draw number in memory. (A congruential method is one in which each successive number is generated by applying an algorithm to the preceding number. As such, given the same starting number, an identical series can be generated.) In this way, the same weather pattern is simulated for all sites in the proximity of any given weather station. The output from the weather simulation is ultimately employed to calculate monthly precipitation and evapotranspiration losses at a site.

The Baseline Analysis element is an integration point wherein all pertinent input points are assembled for a given site. In addition to data supplied by the user and data drawn from the waste and national data bases, the baseline element provides the starting water content.

Water content during the operation is determined by assuming that all infiltration during the operational period enters the system (i.e., no plants are present to cause evapotranspiration, evaporation is minor). Water is then distributed throughout the layers of the site in a manner described in the section on water movement simulation.

The Site Data File is merely a locus wherein the integrated and calculated data inputs from the Baseline Analysis are stored for a given site. The site file acts as a tailored data bank for each site while subsequent analyses are performed.

The Water Movement Simulation submodule is the heart of the breach scenario development mechanism. Basically, this unit models the infiltration of precipitation and subsequent migration of leachate to the point of detection. Because of the random nature of initiating and contributing events, the simulation relies on Monte Carlo techniques. This process begins with the submodule accounting for uncertainties in the seepage velocities, and dispersion

values by drawing values from density curves. These values are used for the rest of a 50-year (or more) simulation.

Having established the initial conditions at a site by either:

1. reading values in from the data base
2. letting the user define the value
3. making a stochastic decision (described above),

the program simulates water movement over time. It begins this process with the output from the weather simulation. Having this information, the program can now account for the water balance in the surface layer, in each month, in the following way:

1. The thickness of the layer is first reduced by an amount indicating monthly erosion loss if post-closure monitoring is no longer active. Erosion loss is based on user specified values when available. If specific loss data are not employed, generalized data for each of the seven prototype designs are taken. Lacking either of these, the state average value is employed from the National Data Base. In all cases, once post-closure care is terminated, erosion losses are accounted for by subtraction of a given amount each month.
2. The amount of raw infiltration (precipitation-runoff) is calculated using a runoff coefficient from the National Data Base.
3. The potential evapotranspiration is calculated using either the Thornthwaite or Blaney-Criddle Method (Thornthwaite and Mather 1957). The choice of method is dependent on the site's geographic location. If the soil cover has been eroded away, then the evapotranspiration is considered negligible because of the subsequent lack of vegetation.
4. The amount of water in the cover layer is reduced if the potential evapotranspiration exceeds the raw infiltration.

If there is a net movement of water into the cover layer beyond its field capacity, then water percolates into the layers below. Like the cover material, the underlying layers exhibit a certain capacity to hold water. In other words, once the field capacity of any layer is reached, it passes any

water it receives to the layer below. The relation is depicted conceptually in Figure 3. The water balance approach taken there is analogous to viewing each layer as a bucket with a finite capacity to hold water. The inflows and outflows of water are calculated at each step. When the bucket is full, it overflows into the next bucket (the underlying layer). This process continues until a bucket with a detection site (monitoring well) or potable use (potable well or surface water) event is recorded.

This approach implicitly assumes that the rate at which the layers can accept water is large enough such that within a time step (i.e., a month), it can accept all the water "offered" to it. This is not necessarily a good assumption for either the clay layers or synthetic layers. Thus, extra consideration is made for these layers. First an estimate for the hydraulic conductivity is found as a function of water content. The driving force moving the water downward (head gradient) is taken as the distance between the mid-point of the two layers. With these values, an estimate of the total amount of water which the clay can accept in a months time can be found. If this amount is less than the "offered" amount, then the smaller amount is accepted into the clay layer and the rest is redistributed in the layer(s) above the clay. If a synthetic layer is intact, it causes the same redistribution of water except that no water is allowed to pass through the synthetic layer. If an active leachate collection system is present, all water in excess of the field capacity for the layer that is not passed by the next lower layer is assumed to be removed by the collection system.

At the end of a simulated year's time, the submodule has an estimate of the volume of water, if any, which has passed through the site for every month of the simulated year. A running sum of the total amount of leachate to date is also kept as is a running total for the volume of water collected in the leachate collection system. The latter can be divided by run time to estimate leachate treatment requirements. If the total amount of water is less than a critical value (defined below), then the calculation goes on to the next year with no calculation made for travel time to the monitoring well. This is because it is assumed that the leachate contaminant is held in the intervening layers between the waste layer and the water table and until these layers are

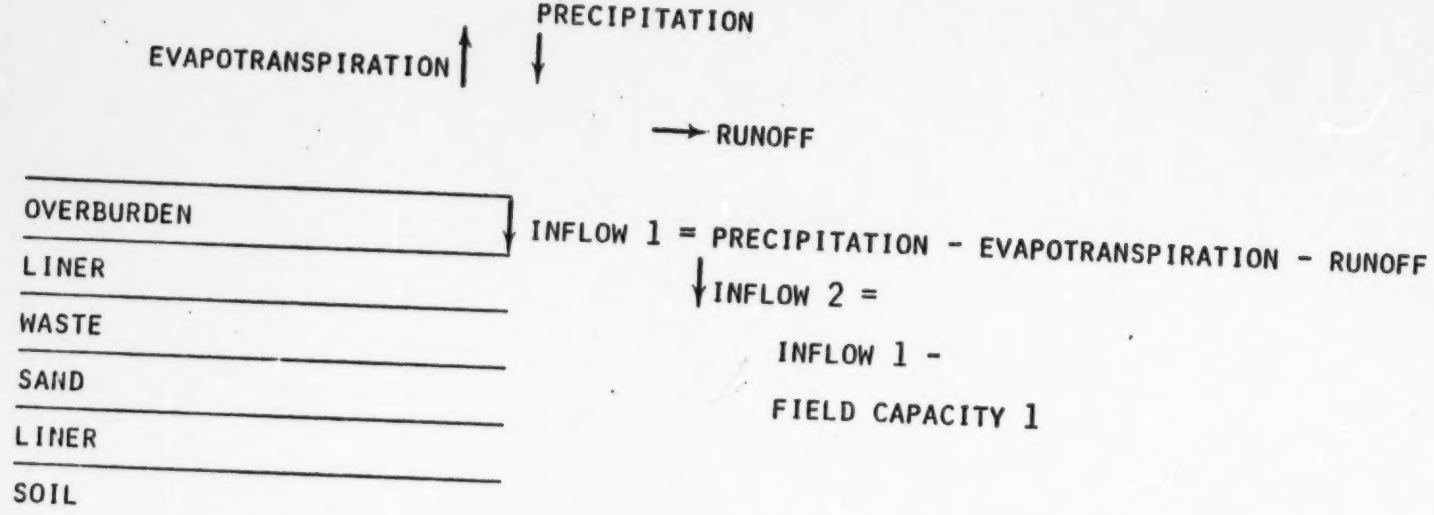

FIGURE 3. Conceptual Model of Water Balance Calculation

saturated with contaminants, no significant movement of waste into the saturated zone will occur. However, if this critical value has been exceeded, the waste enters the groundwater system and dilution effects and travel time to both the monitoring well and the point of potable use are calculated.

The hydrologic transport model is composed of:

1. Landfill Leachate Source Model

   a) The landfill site is assumed to be a two-dimensional leachate source to the unsaturated soil column beneath the site; approximate dimensions of the site are obtained from the input site type.

   b) The leachate discharge (concentration and flux) is assumed to be uniformly distributed over the site at any instant in time; however, the discharge varies with time according to the moisture infiltration of the site.

2. Saturated Zone Transport Model

   a) The leachate plume from the unsaturated zone acts as a two-dimensional horizontal area source on the water table surface to the saturated zone; it is assumed the water flux from the unsaturated zone is insignificant compared to the water flux in the saturated zone, thus, only contaminant particles are released to the saturated zone.

   b) The leachate plume moves through the saturated zone according to a constant value seepage velocity and dispersion coefficient influenced by geochemical retardation of flow and the dispersion model's attenuation in the system.

   c) The transport equation is given by

$$\frac{\partial C}{\partial t} + \left(\frac{Vx}{R}\right)\frac{\partial c}{\partial x} = \left(\frac{Dx}{R}\right)\frac{\partial^2 c}{\partial x}$$

where C = C(x,y,z,t) = leachate concentration
at position (x,y,z) at time t

Vx = seepage velocity of water (x-direction)

Dx = dispersion coefficient of water (x-direction)

R = geochemical retardation coefficient of the leachate

This is expressed in a simple three-dimensional hydrologic transport model that monitors four fronts: (1) the detectable concentration of the first arrival detectable constituent, (2) the toxic concentration of the first arrival toxic constituent, (3) the taste and odor concentration of the first arrival constituent, and (4) the indicator parameter (TDS for inorganics, TOC for organics) concentrations. Initial concentrations are assumed to be at the constituent's solubility level. Dilution and attenuation are accounted for during movement through the soil column and the aquifer. The initial point of detection is assumed to be the monitoring well which is located at the downflow perimeter of the site.

Failure of synthetic liners and covers is determined by Monte Carlo simulation using a probability distribution curve which varies over time. In other words, the probability of rupture increases with the age of the liners. These are: (1) failure due to improper installation, and (2) failure due to "aging." Failure due to improper installation will be calculated using the user inputed probability of improper installation. Failure will then occur at randomly selected sites (based on this probability) beginning at the opening date for liners or the closing date for covers. Failure due to aging is complicated by the lack of any data with which to calculate expected lifetimes. Current EPA publications describing the behavior and performance of synthetic liners do not contain sufficient data accurately to predict liner life [Haxo 1981; Haxo 1982; Matrecon 1980]. An average lifetime of 25 years for synthetic liners and 50 years for synthetic covers is assumed by the module unless overridden by user supplied values. This is based on expected values

for pond liner life reported by Lee (1974) and on the 20-25 year guarantee that many synthetic membrane manufacturers offer for their products. Liners are expected to age faster than covers because of interactions with wastes. It has been observed that waste incompatibility will lead to increased aging of liners. To account for this, waste constituents are classified as polar organics, non-polar organics, or acids, caustics, and salts. If more than one of these waste types is present at a site, it assumed that the liner will age more rapidly than those exposed to a single waste type. If erosion has removed soil over a cover, it is assumed that the cover will then age at the normal rate.

A potential failure mode for clay liners is intrusion by plants and animals. Work is presently being conducted by Battelle Pacific Northwest Laboratories concerning plant and animal intrusion into waste burial grounds. Preliminary results were reviewed as well as results of Hakoson and Gladney (1981). It was concluded that while plant root intrusion to the depths of the waste cover was possible, the effect on permeability would probably be small. The main concern with plant intrusion appears to be with uptake of wastes rather than increased permeability. Therefore, it was decided to ignore plant intrusion. Preliminary work regarding animal intrusion shows that this may have a significant effect if the cover is shallow enough to be in the burrowing zone of animals. Based on preliminary results, it is assumed that animal intrusion will affect 10% of the site area. Using data presented by Moore and Ali (1982) and assuming that the effects of animal intrusions are similar to cracking, the chance of cover failure will be increased by a factor of two following animal intrusion.

Research being performed at Texas A&M University has shown that organic leachates may have a significant effect on the permeability of clay liners. Based on results presented by Anderson, Brown, and Green (1982), the model increases the permeability of clay liners by two orders of magnitude if organic wastes are present in leachate.

OUTPUT

The output from each simulation is the probable timing and type of breach for a given site. Replicate runs are made for each site to generate a probability value for each type of event for each site.

Hence, seven breaches will be included:

- Breach I - Indicator parameters arrive at monitoring well
- Breach II - Detection level for specific contaminants arrive at monitoring well
- Breach III - Toxic level for specific contaminants arrive at monitoring well
- Breach IV - Taste and odor threshold arrives at potable well/surface water
- Breach V - Detection level for specific contaminants arrive at potable well/surface water
- Breach VI - Toxic level for specific contaminants arrive at potable well/surface water
- Breach VII - Infiltration backs up and overflows

In all cases, a flag will note when a breach involves contaminant levels in excess of human health criteria and if the waste includes carcinogens.

This information creates a breach probability table such as that in Figure 4 which is passed on to subsequent modules to determine the concomitant financial demands that would be put on the PCLTF.

	SITE TYPE						
Event Type	1	2	3	4	5	6	7
1	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X
4	X	X	X	X	X	X	X
5	X	X	X	X	X	X	X
6	X	X	X	X	X	X	X
7	X	X	X	X	X	X	X

FIGURE 4. Example Breach Probability Table

DISCUSSION

It should be noted that at this time, the model does not account for acute disruptive events such as earthquakes and extreme storms. Review of causes of hazardous waste mismanagement damage cases showed that these are probably very minor causes of discharges from hazardous waste facilities (Fred C. Hart Associates, 1981).

No special provisions have been made for entry of surface impoundments or land treatment facilities in the model. It is assumed that when closed, these facilities will be treated as landfills if hazardous residuals remain. If residuals do not remain, no significant breach scenarios are evident. Hence, the landfill model will suffice as long as the user provides information on the site design, the moisture content at closing and the nature of the waste.

No special provisions have been made for sites reviewing corrective actions. It is assumed that once corrective actions are specified, the site can be reentered in the system. As currently envisioned, corrective action will consist of two elements: cap/liner repair and withdrawal of contaminated groundwater (counterpumping).

When cap/liner repair is undertaken, the site should be reentered in the simulation as a new site with a design that reflects the repair work. Functionally, the user must specify the new design. The model would then reenter the site and complete the simulation. The default value is to return to the original design for the site.

Withdrawal wells require slightly different treatment. The model is too simple to accommodate well fields to withdraw contaminated water for treatment. However, the effects of withdrawal would not be all that dissimilar to activation of a leachate control system, i.e., termination of all uncontrolled contaminated flows through the liner during the period of pumping. The user must specify how long pumping will be performed. The default value is set as a period equivalent to the time it took for the breach to be discovered in the first place. This is somewhat analagous to the new regulations setting the compliance period equal to the period of operation for a given site. However, it is still a source of inaccuracy. There is no

hysteresis effect in such systems. Desorption may well take much longer than the original adsorption onto soils depending on pumping rates and the contaminants involved. A second area of concern is the residual contamination in the unsaturated zone. Flushing the aquifer does not impact this zone. Hence, a source of concentration would remain below the liners which would effectively accelerate movement of subsequent breaches compared to how the model will simulate the post-remedial action period. The effect is probably small, but it does constitute an inaccuracy.

The model is currently being exercised to provide quantitative output on probable failure modes and consequences for RCRA sites in the future. This will have implications for future landfill regulatory programs as well as the adequacy of the PCLTF.

REFERENCES

Anderson, D., K. W. Brown, and J. Green. 1982. "Effect of Organic Fluids on the Permeability of Clay Soil Liners," Proceedings of the Eighth Annual Symposium on Land Disposal of Hazardous Wastes.

Fred C. Hart Associates. 1981. Assessment of Hazardous Waste Mismanagement Damage Case Histories, Draft, Prepared for EPA Under Contract 68-01-6474.

Hakonson, T. E. and E. S. Gladney. 1981. Biological Intrusion of Low Level-Waste Trench Covers, LA-UR-81-2972, Los Alamos National Laboratory, New Mexico.

Haxo, H. E. 1982. "Effects of Liner Materials of Long-Term Exposure in Waste Environments," Proceedings of the Eighth Annual Research Symposium of Land Disposal: Hazardous Waste, EPA-600/9-82-002, EPA, Cincinnati, Ohio, 191-211.

Haxo, H. E. 1981. "Durability of Liner Materials for Hazardous Waste Disposal Facilities," Proceedings of the Seventh Annual Research Symposium on Land Disposal: Hazardous Waste, EPA-600/9-81-0026, EPA, Cincinnati, Ohio, 140-156.

Lee, J. 1974. "Selecting Membrane Pond Liners," Pollution Engineering, 6, 1, 33-40.

Matrecon, Inc. 1980. Lining of Waste Impoundment and Disposal Facilities, SW-870, EPA, Washington, D.C.

Moore, C. A. and E. M. Ali. 1982. "Permeability of Cracked Clay Liners," Proceedings of the Eighth Annual Symposium on Land Disposal of Hazardous Wastes.

Neely, W. B. Chemicals in the Environment, Marcel Dekker, New York.

Thornthwaite, C. W. and J. R. Mather. 1957. "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance," Publications in Climatology. Laboratory of Climatology, Drexel Institute of Technology, 10, 3, 185-311.